International Journal of Advanced Research in

Electrical and Electronics Engineering

Volume: 3 Issue: 1 26-Jun-2014,ISSN_NO: 2321-4775

Review on High Power Multilevel-Matrix Converters

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ABSTRACT- *Multilevel converters and Matrix converters have been under research and development for more than three decades. They are considered today as the state-of-art power conversion systems for high power and power quality demanding application. However this is still a technology under development and many new contributions and new commercial topologies have been reported in the last few years. The use of multilevel matrix converter in renewable, aerospace, vehicle industry can deeply reduce the cost, weight and increase the reliability for the converters. This paper reviews the history of multilevel and matrix converter and discuss the implementation of a new control strategies.*

Index Terms- Multilevel converter, Matrix converter, Sparse Matrix Converter, Indirect Matrix Converter, Nuetral point converter.

I. INTRODUCTION

Multilevel converters and Matrix converters are a family of power converters extensively researched in industry. In the branch of power converters, it is possible to distinguish two main groups: the converters with energy storage or dc-link and those without [1]. In the first group are the current and voltage source topologies, with which it is possible to obtain ac-ac conversion taking into consideration the presence of a capacitive or inductive dc-link respectively. These structures have been widely studied and they are the converters used in the industry today. In the group of ac-ac circuits without dc-link, different topologies have been reported in the literature and are classified into three main groups: the cycloconverter in a wide power variety, the direct matrix converter (DMC) and indirect matrix converter (IMC). As IMC is a finite commutation state machine predictive control algorithm is simplified to the prediction of every possible switching and application of the best suited one to follow certain references. The review of the recently developed control methods used in Multilevel Converters, Direct matrix converter and Indirect Matrix Converters are reviewed.

II. THE MULTILEVEL TOPOLOGY

Multilevel converters are power conversion systems composed of an array of power semiconductors and capacitive voltage sources that, when properly connected and controlled can generate a multiple step voltage waveform with variable and controllable frequency, phase and amplitude [10].The stepped waveform is synthesized by selecting different voltage levels generated by the proper connection of the load to the different capacitive voltage sources. This connection is performed by the proper switching of the power semiconductors.

Two level converters can generate a variable frequency and amplitude voltage waveform by adjusting a time average of the two voltage levels using PWM (pulse width modulation) techniques[2]. Multilevel converters also has intrinsically improved power quality, characterized by lower voltage distortion (more sinusoidal waveforms), reduced $\frac{dv}{dt}$ and lower common mode voltages, which can reduce or even eliminate the need of output filters.

When the three phases is considered the levels of one phase are combined with those of the other phases, generating more different levels in the line to neutral voltage For a converter with $n_{ll} = 2n_p$-1 levels can be found in the line to line voltage.

While going to the history we can find that the multilevel converter technology started with the introduction of the multilevel stepped waveform concept with a series connected H bridge. It is also known as Cascaded H-Bridge (CHB) converter in the late 60s.This was followed closely by a power development of a flying capacitor(FC) topology same year. Finally in the late 70s the diode clamped converter (DCC) was first introduces. The DCC concept evolved into the three levels Neutral Point Clamped Converter (3L-NPC) we know today as it was considered as the first real multilevel power converter for medium voltage application. Later the CHB would be reintroduced in the late 1980's although it would reach more industrial relevance in the mid 90's .In the same way the early concept of the FC circuit introduced for low power diodes in the 60's developed into the medium voltage multilevel converter topology

Through the years the FC has also been reported as the imbricate –cell and multi-cell converter (the latter is also a name used for the CHB, since both are modular and made by interconnection of power cells. These three multilevel converter topologies could be considered as the classic or traditional multilevel topologies that first made it into real industrial products during the last two decades[20] .Many of the industries are now using these topologies for their applications.

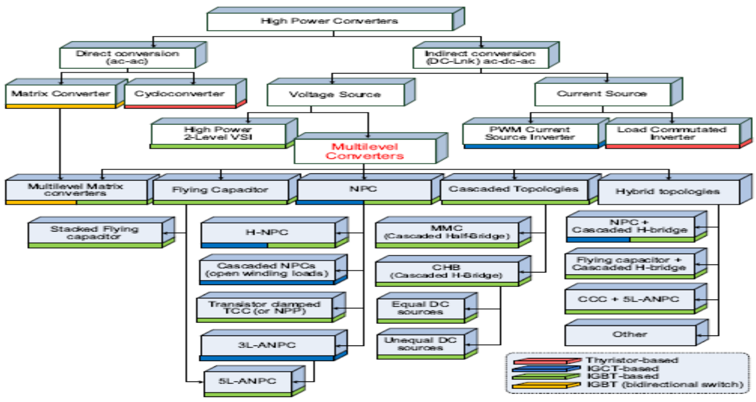

Fig.2.Multilevel converter classification

The operating principles, multilevel waveform generation special characteristics, modulation schemes and other information related to the NPC, FC, and CHB can be found with plenty of details and useful references are available.[15] Furthermore the dc-link capacitors voltage balance becomes unattainable in higher–level topologies with a passive front end when using conventional modulation strategies. In this case the classic multilevel stepped waveform cannot be retained at higher dv/dt's.

III. REVIEW ON MODULAR MULTILEVEL CONVERTER AND MULTILEVEL MATRIX CONVERTERS

A.Modular Multilevel Converter (MMC)

Multilevel converters which recently found industrial applications is the Modulator Multilevel Converter (M2C or MMC), particularly for HVDC systems .This topology was developed in the early 2000s and received attention since then. Three –phase ac-ac and also ac-dc topologies have been proposed[9]. Basically the MMC is composed of single phase two level voltage source converter(2L-VSC) legs ,also known as half–bridges, connected in series as given in Fig 3.The phase leg is divided in two equal sections(number of cells must be even) to be able to generate equal number of positive and negative levels at the ac side. Some inductors are included within each leg to protect during transistor short circuits

The two switches of the power cell are controlled with complementary signals and produce two active switching states. They can connect or bypass its respective capacitors to the total array of capacitors of the converter leg. Thus generating,the multilevel waveform. There is a third switching state: both switches off that is used during start up or failure conditions, allowing the current to circulate freely through the diodes(and through capacitors if so demanded by the current polarity)

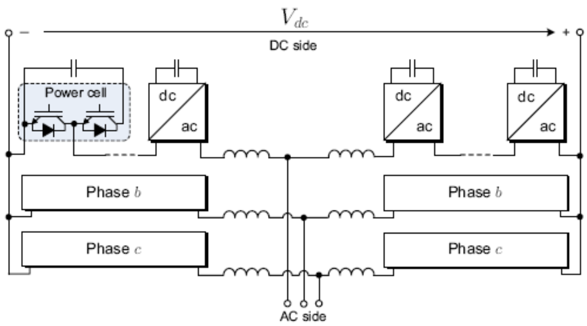

Fig.3. Modular Multilevel Converter (M2C or MMC)

Since the capacitors are floating, an approximate voltage balance control is also necessary to keep each one at a constant voltage level.[19] The total dc side will be the sum of all the capacitor voltages in one leg. The attractive feature of this topology is its modularity and scalability to reach easily medium and high voltage levels, meanwhile greatly improving ac side power quality compared to classic series connection of power switches in a two-level converter configuration used in HVDC(also the uneven voltage sharing problem between series connected devices is solved.

B.Multilevel Matrix Converters

The matrix converter belongs to the direct conversion family of converters. It connects directly the input ac lines to the output ac lines through bidirectional switches and without need of energy storage devices like capacitors or inductors. As a consequence, their strengths are an important weight/volume reduction and inherent four quadrant operation which are desirable features for transportation systems (electric vehicles, more electric aircraft, military vehicles etc)[15]

The cascaded matrix converter is the only one that effectively increases the power rating of the conveter.Like the CHB, this topology elevates the voltage by the series connection of power transformer that provides isolated and phase shifting power transformer that provides isolated and phase shifted three phase secondary ac sources that are connected to the load side by a power cell composed of a 3×2matrix converter and its corresponding three-phase input capacitive filter.

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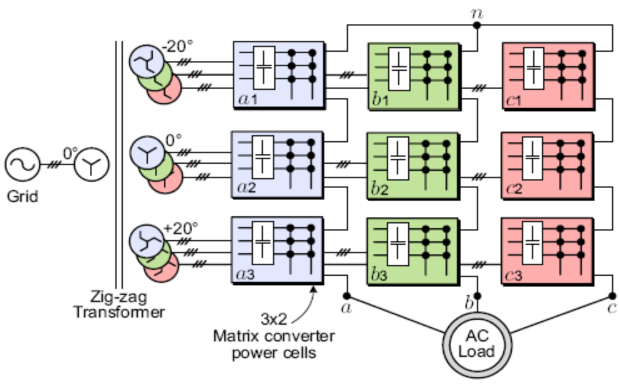
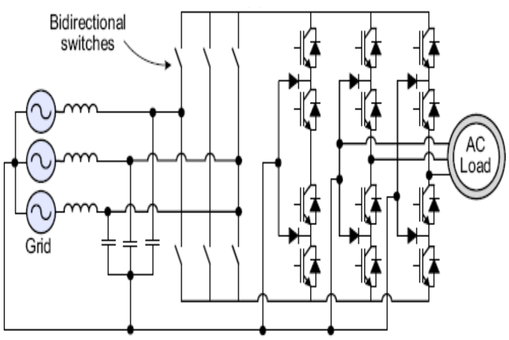


Fig .4(a). Cascaded Matrix Converter

The series connection of the two output lines of the cells is possible due to the isolation of the ac inputs provided by the transformer .The phase shifting transformer not only supplies isolated ac sources but the phase shift has a multipulse effect reducing the input current harmonics,just as with the CHB.



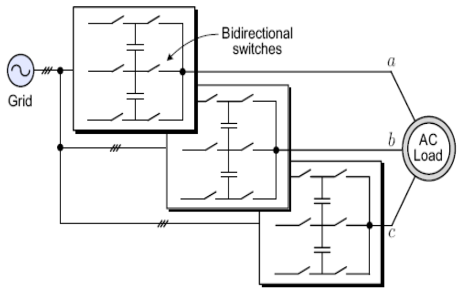


Fig.4 (b). Indirect Mat rix Converter-NPC

Fig.4(c). Flying Capacitor Matrix Converter

In addition the phase shifts at the secondary side produce the effect of having a multiphase ac source (6 phases for a 2 cell converter,9 phases for a 3-cell converter) that enables the generation of more output voltage levels.The proper control of the switching states produces a stepped multilevel output voltage waveform at the load side.

IV. MATRIX CONVERTER TOPOLOGY

Matrix Converters are an array of controlled switches that directly connect each input phase to each output phase without an intermediate link and no bulky elements, which are subjected to ageing. Earlier the voltage transfer ratio was limited to 0.5, with the help of third harmonic injection techniques ,the maximum voltage transfer ratio was increased up to 0.866[12]. Full control of the input power factor can be achieved through SVM [11]; it can also completely utilize the input voltages and improve the modulation performance. Based on the concept of duty cycle space vector, allows an immediate comprehension of all degrees of freedom that affect the modulation strategies.

Earlier bidirectional switches were obtained combining discrete components. Then manufacturers produced power modules specifically for matrix converters. Traditional silicon IGBT and with silicon carbide diodes came to market by 1980's.The performance of switches has been compared in many technical comparison [13]

A.Input Filter

This is generally needed to smooth the input currents and to satisfy the EMI requirements. A reactive current flows through the input filter capacitor leading to a reduction of the power factor especially at low output power. The capacitor is chosen to ensure at least a power factor for 0.8 with 10% of rated output power. It is after the selection of capacitor the input filter inductance of the matrix converter is chosen. The bidirectional switches used in the MC should have the ability to block the voltages and conduct the current in both directions. There are two main topologies for bidirectional switches

[1] Common Emitter anti parallel IGBT configuration
[2] Common collector antiparallel IGBT configurations

B.Common Emitter arrangement

In this two IGBT's are connected with two diodes in an anitparallel configuration .The diodes provide the reverse blocking capability. The complete connection scheme of this solution is that the two IGBT can be driven with respect the same point.i.e. The same common emitter that can be considered as a local ground for the bidirectional switch. On the other hand each bidirectional switch requires an insulated power supply, in order to ensure a correct operation and hence, a total of nine insulated power supplies are needed.

The power supplies must be insulated because as a bidirectional switch is turned on, the common emitter assumes the potential of an input phase .Therefore it's not possible to drive all the switches to the same common point.

The manufacturers have developed integrated power modules for Scale the traditional solution consists of a single power module containing the switches corresponding to one leg of the converter**.** Modules with whole power stage are also present. (EUPEC). [5]The traditional solution instead requires four of the six insulated voltages that are necessary for Common collector configuration. A major challenge in MC is current commutation, MC doesn't have freewheeling diodes, unlike VSI, so the current commutation between switches is a difficult task, and the commutation has to be continuously controlled. The switches have to be turned on and off in order to avoid short circuit and sudden current interruptions. Many commutation strategies have already been studied the most common solution is 4 step commutation.

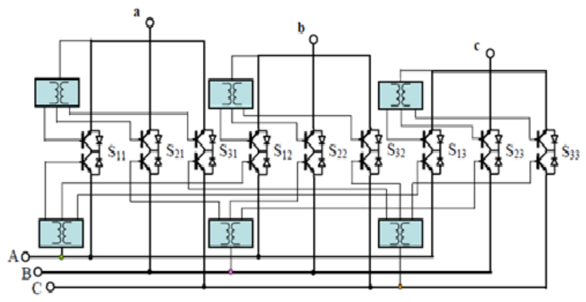


Fig.6. Complete scheme of power stage using common collector arrangement.

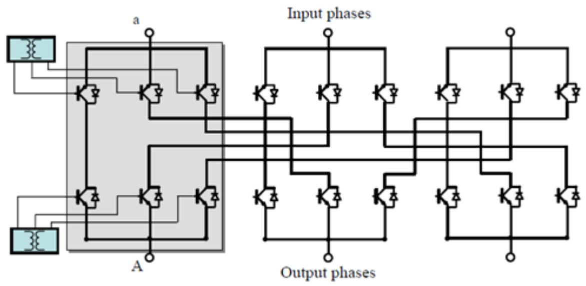


Fig.7.Common collector configuration with 2 insulated power supplies per phase

That requires information about the actual current direction in the output phases. As per the figure shown below, is the general case of current commutation from “a” bidirectional switch a to bidirectional switch “b”

V.REVIEW OF DIRECT MATRIX CONVERTER AND INDIRECT MATRIX CONVERTER WITH MODULATION STRATEGIES

A conventional matrix converter does employ 9 bidirectional bipolar (four quadrant) switches which, based on available power semiconductor technology have to be formed by 18 unipolar turn off power semiconductors and 18 diodes as shown in Fig.11(a).The combination of 2 IGBT and 2 anti- parallel diodes per four quadrant switch does allow a selective turn-on of the switch for each current direction as required for the implementation of safe multi step commutation strategy avoiding the short circuiting of an input line-to-line voltage or an abrupt interruption of an output phase current.

. The novel converter topology do show a reduced number of power transistors denoted as sparse matrix converter(SMC)or ultra sparse matrix converter(USMC) . For the derivation of the SMC first the CMC has to be reviewed

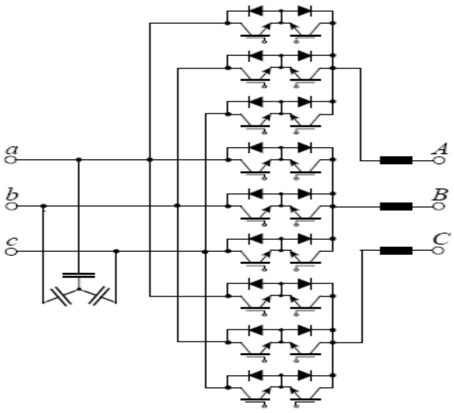


Fig.11(a). Conventional matrix converter

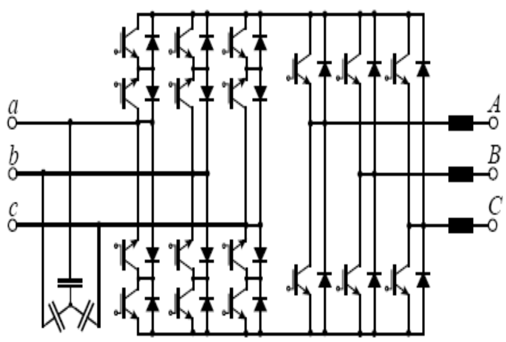


Fig.11(b). Indirect matrix converter

For the IMC a conventional (two-quadrant switch) voltage source-type inverter is fed by a four quadrant switch current source type rectifier which is able to operate with positive and negative DC current for unipolar DC link voltage as required by the inverter stage. There the input capacitor of the inverter has to be thought to be realized by the AC-side filter capacitor of the rectifier stage and output inductor of the rectifier is realized by current impressing inductance of the load. The IMC does employ 18 unipolar turn-off power semiconductors and 18 diodes,

Converter Type	Transistor	Diodes	Isolated Driver Potentials
CMC	18	18	6
IMC	18	18	8
SMC	15	18	7
VSMC	12	30	10
USMC	9	18	7

Table 1.Comparision of different matrix converter topologies

The DC link voltage of the IMC shows a fixed polarity but the IMC four-quadrant switch current-source-type rectifier could operate with both DC link voltage polarities .Therefore it is near at hand to consider ways of reducing the rectifier stage circuit complexity. The actual possibility of a reduction of the number of unipolar turn off power semiconductors of the current –source type rectifier stage is verified step by step as given below.

For $s_{pa} = s_{ap} = 1$ (a switching function s_i=1 does denote a turn –on state of the corresponding power transistor $S_{i,}s_i = 0$ does denote a turn off state) for the bridge leg topology shown in Fig.12(a) input a is connected bidirectionally to p.There is case $u_{pn} > 0$ transistor S_{an} is the blocking voltage,a voltage $u_{pn} < 0$ is taken over by $S_{na} > 0$ Restricting the operation to $u_{pn} > 0$,therefore a blocking S_{na} with the turn on interval of S_{ap} is not required and both transistors could be combined in a single transistor S_a which has to be turned on for the connection of a to p as well as connecting a to n[15].However ,the resulting bridge leg topology for $u_{pn} > 0$ still does provide the independent controllability of both current directions as required for the implementation of a safe commutation strategy[paper].As for $u_{pn} > 0$ the functionality of an IMC and/or CMC can be realized by the novel converter topology depicted in Fig. which employ only 15 IGBTs as opposed to 18 IGBT of the IMC and does require a lower number of isolated gate drive power supplies and therefore shall be denoted as Sparse Matrix Converter(SMC)

With reference to an unidirectional buck-type PWM rectifier system, one now could further reduce the realization effort of the SMC by omitting the power transistors S_{pi} and S_{in} in each bridge leg i=a,b,c which do provide a reversibility of the DC link current , this basically restrict the circuit operation to unidirectional power flow ($u_{pn>}0, i > 0$).

Volume: 3 Issue: 1 26-Jun-2014,ISSN_NO: 2321-4775

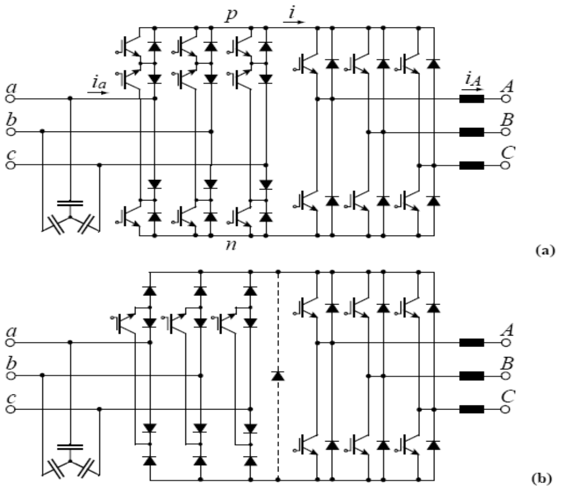


Fig.13. (a) Sparse matrix converter and.
(b) ultra sparse matrix converter

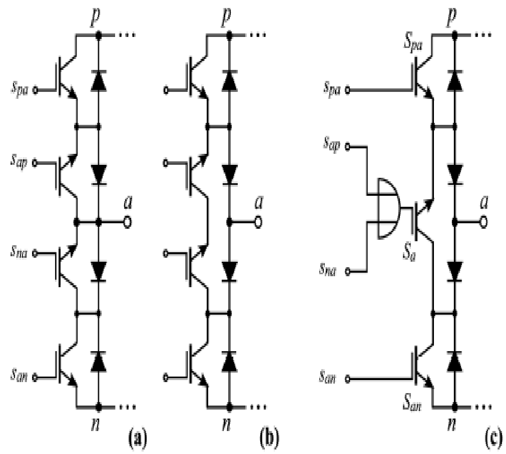


Fig.12.Realization of structure of a bridge leg of the type rectifier input stage of IMC (a) into and SMC leg topology(c)

Due to the low number of power transistors the novel circuit topology which is denoted as Ultra Sparse Matrix Converter (USMC).

VI. CONCLUSION

This paper summarizes and reviews the various types of Multilevel Converter topology and also modular topology in multilevel converter. The disadvantages and advantages of the modular converters are also widely discussed. The introduction of Matrix converter topology into the multilevel converters is also summarized.

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